NASA TECH BRIEF

Nonlinear Damping in Structures

To predict the dynamic responses of a structure quantitatively, its damping properties must be known to a high degree of accuracy. However, a uniform set of definitions for structural damping properties is not available, despite the universally recognized need for such data.

An analytical and experimental study of the dynamic responses of a structure with nonlinear and nonproportional damping has been completed. The analysis showed that the steady-state solution of a structure with damping at its boundary can be obtained from the undamped vibration solutions, and that if nonproportional damping is low, classical normal mode responses can be indicated by the derived general solution. Analytical results were used to develop experimental approaches to determine damping properties of substructures or structural elements. Experimental studies were used to demonstrate the developed techniques, and results proved the feasibility of measuring damping for its components and for obtaining an accurate overall structural damping prediction. While the analyses and experiments were confined to a beam-like structure, they could be adapted easily to other configurations commonly encountered in industrial structures.

For complicated structures, it is impractical to determine local damping properties from dynamic tests of the assembled structure, primarily because many actual dissipative processes in structures are nonlinear in nature, and because the distribution of damping mechanisms is usually not proportional to any linear combination of inertia and stiffness matrices. Consequently, the responses of such structures are not solutions of uncoupled modal equations of motion, and local damping properties must be determined by physical substructuring and testing. In general, a substructure or structural element can be so chosen for damping and stiffness measurements that it contains only one relatively simple, continuous member with one or more boundary conditions representing mechanical joints used to connect the substructure with others in the parent structure. For the substructure, damping is due to dissipations which occur within material elements, across joint interfaces (including boundary joints), and over solid-fluid interfaces. In most cases, damping for the substructure is still nonviscous, amplitude-dependent and nonproportional. Because of the simplicity of the substructure, however, the analyses required for damping property measuring experiments can be developed, even with such complications. This is the principal advantage of testing substructures rather than complete structures.

To predict dynamic responses of the parent structure, modeling (analytical representation) of structural elements presents relatively minor difficulties, especially in light of recent developments in applications of final element methods. The success or failure of an analysis is critically dependent upon success or failure in modeling structural joints, particularly in assigning correct stiffness and damping values for joints. Substructure and joint testing will provide the desired information which cannot be easily obtained by any other means. A strong case can be presented for preferring analyses (or model testing) in combination with substructure tests, over performing full-scale tests on the basis of better accuracy and more meaningful results attainable, usually at lower costs. The analysis of a simple beam with a dissipative end condition led to simple solutions that are easily related to physical properties of the structure. The method of analysis appears to be equally applicable

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for other structural components, as well as for substructures of greater complexity than rods, beams and plates. Based on such considerations, definition of modal responses and modal coefficients, etc., (which can be related to physical properties of structures) were proposed for the case of nonproportional damping. If nonproportionality is small, modal coefficients can be assumed to be constant even if total damping is not low.

The experimental demonstration of the test approach of physically substructuring complicated structures and testing them and joints individually was successful for the specimens employed. This success leads to the postulation that substructure testing and analyses may eventually replace expensive tests of totally assembled complex structures. Advantages of substructure testing are clear: local properties are directly measured, and specimens are less costly and more easily tested with better controlled tests and environments.

Notes:

1. This modeling technique presents a relatively uncomplicated method for analysis of real-case models, and may be of use wherever complex vibratory problems are encountered. The information should interest personnel in the aircraft, marine and high speed ground transportation industries, and manufacturers of high speed machinery.
2. Requests for further information may be directed to:

   Technology Utilization Officer
   Marshall Space Flight Center
   Huntsville, Alabama 35812
   Reference: TSP70-10341

Patent status:

No patent action is contemplated by NASA.

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